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Optimization Sizing and Economic Analysis for Stand Alone Photovoltaic System with Hydrogen Storage

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ABSTRACT

Photovoltaic system has a high potential in the future, since it is clean, environmental friendly and has secure energy sources. However, the intermittence behavior in photovoltaic resource due to their strong dependency on climatic and meteorological conditions made the essential of having energy storage as a backup power supply. This paper proposes a design steps in obtaining the optimal sizing of standalone photovoltaic system, which able to meet a pre-determined power load requirement close to its point of utilization. The keys of system design were, primarily, to satisfy a specific load demand that depends on the power generated from installed PV system and also to maintain hydrogen storage state of charge. A case study was conducted using Kuala Lumpur's meteorological data and typical rural area daily load profile of 2.215kWh. An economic analysis on the system was performed in order to determine system feasibility. The finding shows that the levelized cost of energy for proposed system is RM 1.98/kWh. However, the results of the study showed that if the same configuration is using AGM battery as back-up supply, the system cost is lower and more economically viable, unless the cost of hydrogen storage technologies significantly reduced in the future.

Key Words: Stand alone power system; Photovoltaic Generation; Hydrogen Storage; Economic Analysis.

1. INTRODUCTION

World's electricity production is mostly depends on coal, oil and natural gas as power supply. Due to limited reserves of fuels, their unstable prices, and global warming risks cause the interest in renewable energy sources significantly increase. Renewable energy usage is proven to reduces the dependency on fossil fuels, since it has great potential, clean, and abundantly available [1].

Among the alternatives energy available in Malaysia, photovoltaic (PV) system is the most promising renewable energy in Malaysia. The country is located in Southeast Asia, positioned in equatorial zone between 100˚ to 120˚ in east longitude, and between 1˚ to 7˚ in north latitude. Therefore, this country is blessed with high intensity solar energy with an average daily temperature varies from 21˚C to 32˚C [2]. However, because of its fluctuation nature, stand alone photovoltaic (SAPV) system need other supplemental power sources such as storage batteries to supply power continuously.

Integrating PV with hydrogen storage leads to non-polluting reliable energy sources. In the system, hydrogen is produced by electrolysis process powered by the excess electrical energy from PV generation, and then stored in hydrogen tank. In the periods when load demand is higher than generated energy from PV system, the stored hydrogen and air are fed into a fuel cell (FC), then opposite of electrolysis process takes place, and energy will be supplied [3].

Therefore, it is important to find optimum design before actual installation. This is to ensure that the system will not be oversize or undersize. After that, economic analysis was done to determine system feasibility and economically utilize the solar energy and hydrogen storage [4, 5].

This paper presents a sizing method and economic analysis for hypothetical case using typical residential load demand in Malaysia. Details calculation for system sizing, configuration and arrangement are discussed in the following sections. The Levelized Cost of Energy (LCOE) are calculated once the system best configuration has been identified.

This paper presents an optimization method and economic analysis of SAPV system with hydrogen storage for hypothetical case using typical residential load demand in Malaysia. A case study was conducted using Kuala Lumpur's meteorological data and typical rural area daily load profile of 2.215kWh. Details configuration, system sizing, and economic analysis are performed and discussed in the next sections.

2. SYSTEM CONFIGURATION

Figure 1 shows the suggested configuration SAPV system with hydrogen storage in Malaysia. During the day, PV array will converts sunlight into DC power. If PV array produces higher power than load demand, the surplus power goes to electrolyser. Electrolyser uses the excess power to converts water into hydrogen and oxygen gasses. The hydrogen gas stored in hydrogen storage, and oxygen released to the air. In the other hand, during insufficient PV power, fuel cell draws hydrogen from the storage tank and oxygen from the air, and convert both gasses into water again in order to produce power to serves load demand. DC bus voltage is nominal voltages for PV array, hydrogen storage system, and DC appliance. Most installers will use 12 VDC, 24 VDC, 36 VDC or 48 VDC for off grid system. Inverter converts DC power into AC power to match AC bus and AC appliances.

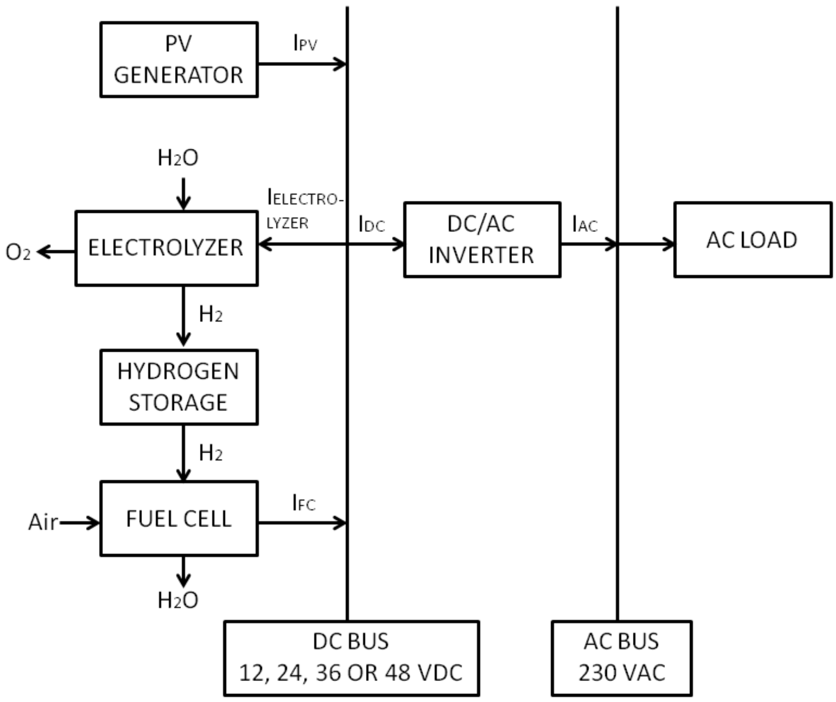

Figure 1: 30 System Configuration for SAPV with Hydrogen Storage

2.1. Solar Energy Resources Forecast

The prediction accuracy of PV power in has great significance in system design. Energy output from the proposed system is predicted by an inclusive study on meteorological condition at installed generation system. It is because the performance of PV modules is strongly depending on the sun light condition and cell temperature [6].

Solar radiation data often measured in horizontal plane without obstacle or shading. In this paper, meteorological data was imported from Meteonorm 6.1, using PVsyst V6.10 software. PVsyst V6.10 software is mainly used as an analysis, planning, design, and sizing tool. This software has its own Meteo database, and able to import data from websites. Meanwhile, Meteonorm 6.1 is a comprehensive meteorological reference that has a meteorological forecast model to calculate hourly and minute value from monthly data for any sites. Table 1 shows the average annual of global irradiation in Malaysia at horizontal plane, generated from PVsyst software [7].

For this analysis, monthly average annual irradiation and PSH data from Kuala Lumpur was generated by PVsyst V6.10, as shown in Table 2 [7]. The annual global irradiation for Kuala Lumpur is 1655.59 kWh/m^2, maximum average annual irradiance over a year, H_{Smax} is 205.11 W/m^2 (March) and the lowest monthly daily's peak sun hour, PSH_{lowest} is 4.081 h/day (December).

Table 1 Annual Global Radiation in Malaysia [7]

State	Global Irradiation, kWh/m²	State	Global Radiation, kWh/m²
Kuala Lumpur	1655.59	Negeri Sembilan	1650.40
Labuan	1792.10	Pahang	1675.50
Putrajaya	1654.60	Perak	1760.00
Terengganu	1771.49	Perlis	1788.50
Johor	1637.32	Pulau Pinang	1794.90
Kedah	1795.90	Sabah	1733.23
Kelantan	1782.71	Sarawak	1579.58

Table 2 Monthly Average Annual Irradiation and Daily's Peak Sun Hour in Kuala Lumpur [7]

Month	Average Annual Irradiance, W/m²	Peak Sun Hour (h)	Month	Average Annual Irradiance, W/m²	Peak Sun Hour (h)
January	179.839	4.319	July	188.978	4.535
February	202.976	4.871	August	186.962	4.487
March	205.511	4.945	September	187.778	4.513
April	199.861	4.800	October	190.860	4.584
May	194.892	4.681	November	171.944	4.127
June	187.639	4.513	December	170.027	4.081

2.2. Load Demand

Table 3 presents load profile for a typical house in rural area in Malaysia. It is assumed that the energy requirement remains the same for each for a year period [8]. The load profile is consist 2.215 kWh with varies AC home appliances.

Table 3 Load Demand for a Typical House of Rural Area in Malaysia

Appliance	Voltage (V)	Power (W)	Daily Usage (h)	Energy (Wh)
Flourescent Lamp 1	230	20	10	200
Flourescent Lamp 2	230	40	4	160

TV	230	60	5	300
Refrigerator	230	50	24	1200
Radio Cassette	230	10	11	110
Ceiling Fan	230	60	2	120
Desk Fan	230	25	5	125
Total		265		2215

3. SYSTEM DESIGN

This section shows the system design and calculation needed to determine the required capacity for SAPV system components. The analysis will be done in Amp-hour method. The advantages of Amp-hour analysis is it takes account the real world behaviour of the components [9].

3.1. Estimate Load Demand

Design process start with estimation of total daily energy requirement. First, a list of lights and home appliances, as well as their individual total usage in hours per day is needed. Daily AC energy demand, E_{AC} is calculated. Extra amount of energy is needed to cover losses, due to inefficiencies in cables, modules, batteries, charge controller and inverter. Calculation of AC energy losses and total daily energy requirement is as shown in Equation 1 and 2, where $\eta_{AClosses}$ is 0.35 [9].

$$AC_{losses} = E_{AC} * \eta_{AClosses} \tag{1}$$

$$E_{req} = AC_{losses} + E_{AC} \tag{2}$$

Daily system charge requirement, Q_{req} (Ah) is calculated using Equation 3, where V_{DCbus} is the selected DC bus voltage.

$$Q_{req} = \frac{E_{req}}{V_{DCbus}} \tag{3}$$

3.2. PV Array Selection and Sizing

PV array capacity must be able to meet total daily load demand plus extra energy to cover system losses. Before sizing PV arrays, designers need to estimate solar energy available at the site. The month with the lowest PSH (h), PSH_{lowest} is selected as design month. Array size must be match with total daily energy requirement. Therefore, by using Q_{req} (Ah) obtained, system charging current from PV array, I_{charge} (A) is calculated using Equation 4 [9].

$$I_{charge} = \frac{Q_{req}}{PSH_{lowest}} \tag{4}$$

The modules connection and arrangement was determined based on preselect PV model [10]. The number of parallel string, N_p was calculated as Equation 5, where I_{mp} is module's current maximum power. Next, Equation 6 is used to calculate series-connected modules in each parallel string, $N_{mod/strg}$, where V_{mod_rated} is module's rated voltage. Lastly, total PV modules, N_{PV} can be calculated using Equation 7 [9]:

$$N_p = roundup\left(\frac{I_{charge}}{I_{STC}}\right) \tag{5}$$

$$N_{mod/strg} = \frac{V_{mod\_rated}}{V_{DCbus}} \tag{6}$$

$$N_{PV} = N_p * N_{mod/strg} \tag{7}$$

3.3. Proton Exchange Membrane Electrolyser (PEME) Sizing

The most used technologies among water electrolysers are Alkaline and Proton Exchange Membrane Electrolyser (PEME). Commercially available PEME can produce from 400 to 7900 kg of hydrogen EACH year with pressure generation up to 13.8 bar. Meanwhile, alkaline electrolyser produce 2400-71000 kg over a year. The advantage of PEME technology is it has high energy efficiency for each stack (75%-88%) with 5% as required minimum output flow for a safe operation [11].

An electrolyser decomposes water into hydrogen and oxygen by passing an electrical current (DC) between two electrode separated by an aqueous electrolyte with good ionic conductivity. The reactions take place at the anode and the cathode of electrolyser as follows [12].

Anode: $$H_2O \rightarrow \frac{1}{2}O_2 + 2H^+ + 2e^- \tag{8}$$

Cathode: $$2H^+ + 2e^- \rightarrow H_2 \tag{9}$$

Storage charge capacity required, Q_{storeq} is calculated based on Equation 10 [9, 13], where N_c is battery's reserved days, and *DOD* is battery's depth of discharge. N_c usually set as 1- 4 days, and it is advised that battery's depth of discharge should not be over 60%. Meanwhile, energy storage consumption, E_{storeq} is the amount of energy consumed to produce required hydrogen, and calculated using Equation 11, where η_{Elz} is electrolyser efficiency, and η_{FC} is fuel cell efficiency. The value of η_{Elz} is 0.88 and η_{FC} is 0.6.

$$Q_{storeq} = \frac{Q_{req} * N_c}{DOD} \tag{10}$$

$$E_{storeq} = \frac{Q_{stpreq} * V_{DCbus}}{\eta_{Elz} * \eta_{FC}} \tag{11}$$

Meanwhile, the rated power for the electrolyser, P_{Elz} is equal to the maximum excess in the PV generation power over the minimum load power; which can be calculated using Equation 12, where A_{PV} is PV panel area, and η_{PV} is PV panel efficiency [11, 14].

$$P_{Elz} = H_{S\,max} * A_{PV} * \eta_{PV} \tag{12}$$

3.4. H_2 Storage Tank Sizing

Hydrogen can either be stored in liquid or gas condition. Liquid hydrogen is stored in cryogenic tanks and gaseous hydrogen stored in either medium or high-pressure cylinders or near atmospheric pressure in metal hydrides.

The hydrogen formed by the electrolyser during each month is calculated by assuming that the produced hydrogen is stored completely before it supplies power to the residential load. The amount of hydrogen produced annually is the total excess of PV power transformed into volume, which expressed in m^3 [14].

Equation 13 is the hydrogen mass required to produce the specific electrical energy, m_{h2} where *HHV* is higher heating values of hydrgogen (39.44 kWh/kg). The hydrogen's required volume capacity, V_{h2} is calculated in the next equation, where M_c is margin coefficient for compressor and storage hydrogen leakage compensation and ρ_{h2} is hydrogen density. Value of M_c is greater than 1.1 and ρ_{h2} is 0.089 kg/m^2 [11].

$$m_{h_2} = \frac{E_{storeq}}{HHV} \tag{13}$$

$$V_{h_2} = \frac{m_{h_2}}{M_c * \rho_{h_2}} \tag{14}$$

3.5. Proton Exchange Membrane Fuel Cell (PEMFC) Sizing

The opposite reaction occurs in the electrolyser take place in fuel cell. Hydrogen in the anode is ionized releasing electrons and protons. Electrons flow to the cathode through a circuit producing electric current. Protons diffuse through a polymer electrolyte membrane and react at cathode with oxygen and electrons to form water. The chemical reactions happened in PEMFC are as below [12].

Anode: $$H_2 \rightarrow 2H^+ + 2e^- \tag{15}$$

Cathode: $$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O \tag{16}$$

The following equation are fuel cell sizing by considering maximum AC load power in the household, where M_{FC} is margin coefficient of the fuel cell, P_{ACload} is total power from AC load demand and η_{inv} is inverter efficiency [14].

$$P_{FC} = M_{FC} * \frac{P_{ACload}}{\eta_{inv}} \tag{17}$$

3.6. Inverter Selection and Sizing

Inverter is expected to deliver maximum AC load in household. Hence, inverter power rating , P_{inv} is selected using Equation 18, where 1.25 is set as oversized factor [15].

$$P_{inv} = P_{ACload} * 1.25 \tag{18}$$

4. ECONOMIC ANALYSIS

The viability of proposed system can be determined by using economic analysis. The designer will know whether the investment is acceptable or not. For this paper, life cycle cost (LCC) and levelized cost of energy (LCOE) is used to analyze system practicality. LCC is the sum of installation cost, operating and maintenance of an item for a period of time, and replacement cost in present value [16], which calculated using Equation 19,

$$\begin{aligned} LCC &= C_{pv} + C_{controller} + C_{inv} + \\ &C_{install} + C_{invrep} + C_{O\&M\_20years} - C_{salvage} \end{aligned} \tag{19}$$

where C_{pv} is PV array cost, $C_{storage}$ is hydrogen storage cost, C_{inv} is inverter cost, $C_{install}$ is installation cost, C_{invrep} is present values for inverter replacement, $C_{O\&M\_20years}$ is present worth of operation and maintenance cost for 20 year and $C_{salvage}$ is system's salvage value.

Beside inverter, all of other components considered to have 20 years of lifetime. Inverter needs replacement after 10 years, and replacement for inverter, C_{invrep} is calculated by Equation 20. $C_{O\&M\_22years}$ is calculated using Equation 212 [17, 18].

$$C_{invrep} = C_{inv}\left(\frac{1}{1+i}\right)^N \quad (20)$$

$$C_{O\&M\_20years} = (C_{O\&M})*\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] \quad (21)$$

where N is component's lifetime and i is market rate. $C_{O\&M}$ is operation and maintenance cost for each year and it is predicted to be 1% from total initial cost. Market interest rate, i is calculated using Equation 22, where i' is real interest rates determined by local bank. i' is calculated as Equation 23 [19]:

$$i = i' + \overline{f} - i'\,\overline{f} \quad (22)$$

$$i' = BLB - 2\% \quad (23)$$

where BLB is Base Lending Rates, and $\overline{f}$ is inflation rate. Based on [20], inflation rate for Malaysia in May 2014 is 3.4%, and BLB is 6.6% [21].

LCOE (RM/kWh) is defined as the average cost per kWh of electrical energy produced by PV system [22]. It is calculated by dividing annualized life cycle cost, LCC_{1year} with total useful electrical energy generated, $E_{PV,}$ as calculated by the following equations [23]. In economic analysis calculation, market price for the proposed system's components are summarized as Table 4 [5, 11, 18, 24-27].

$$LCC_{1year} = \frac{LCC}{\left[\frac{(1+i)^N}{i(1+i)^N}\right]} \quad (25)$$

$$LCOE = \frac{LCC_{1year}}{E_{PV}} \quad (26)$$

$$E_{PV} = N_{PV} * P_{mp\_STC} * PSH_{year} \quad (27)$$

Table 4 Components' Pricing [5, 11, 18, 24-27].

Components	Model	Unit	RM
Solar Panel	KD140GX-LFBS	1	886.17
Inverter	Cotek SK350-224	1	560.71
PEME		RM/W	4.44
H2 Storage Tank		RM/Nm3	77.88
PEMFC		RM/W	1.02
Support Structure & Installation cost		RM/Wp	4.00

5. SYSTEM COMPONENTS

Figure 1 in the previous section shows the suggestion configuration of involved components in SAPV system with hydrogen storage. This section shows the selected commercialized PV panel and inverter used in sizing and analysis.

5.1. Photovoltaic Array

For PV module, Kyocera KD140GX-LFBS was chosen for the analysis, since it is suitable for rural applications. It is multi-crystal cell module, and it's rated power in standard test condition (STC), P_{mp_STC} is 140 Wp. Since it has 12 V nominal voltages, the module will be connected two units in series, to match 24 VDC bus voltages. Its nominal STC current, I_{STC} is 7.91 A and short circuit current, I_{sc} is 8.68 A. The module's dimension is 1.5 m x 0.668 m [25].

5.2. Inverter

A suitable inverter selected to match above charge controller and AC load is Cotek SK350-224. It has rated power of 350W and 94% efficiency. The inverter is suitable to convert 24 VDC power into 230 VAC. Its rated power is 350W. This inverter commonly used in home and office appliance, power tools and portable equipment, vehicle and solar power system [27].

6. RESULTS AND ANALYSIS

This section shows the system sizing result and economic analysis for a project lifetime of 20 years.

6.1. System Sizing Results

Table 5 below shows technical data of each component. A combination of 8 units of KD140GX-LFBS modules and one unit of Cotek SK350-224 inverter were chosen as the proposed SAPV system. However, this paper presents the sizing of hydrogen storage system generally, since it is not widely commercialized yet.

Table 5 Proposed System Sizing

Daily System Energy Requirement		
Total Daily AC Energy Demand	2215.00	Wh
AC losses	775.25	Wh
Total Daily System Energy Requirement	2990.25	Wh
System Voltage	24.00	VDC
Daily System Charge Requirement	124.59	Ah
Sizing and Choosing the Modules		
Lowest Daily's Peak sun hours	4.08	h
System Design Charging Current	30.53	Amps
Details of Selected Modules		
Model	Kyocera KD140	
Peak Watts	140.00	Wp
Rated Voltage	12.00	VDC
Maximum Power Rated Current	7.91	Amps
Short Circuit Current	8.68	Amps
PV Efficiency	20.40	%
Number of Parallel String	4	
Number of Modules/ String	2	

Num of Modules	8	
PV Array Area	8.016	
Hydrogen Storage Sizing and Selection		
Daily System Charge Requirement	124.59	Ah
Reserve Days	2	day
Maximum DOD	50	%
Required System Battery Capacity	498.38	Ah
Details of PEME Sizing		
Energy Storage of Electrolyser	22653.4	Wh
Rated Power of Electrolyser	335.409	W
Details of H2 Sizing		
Mass of Hydrogen	5.63463	N
Volume of Hydrogen	57.555	m3
Hydrogen Storage Capacity	324.301	Nm3
Details of PEMFC Sizing		
Rated Power of Fuel Cell	284.946	W
Inverter Sizing and Selection		
Maximum Power AC Load	265	W
Inverter Rating	340	W
Details of Selected Inverter		
Model	Cotek	SK350-224
Rated Voltage	24/230	VDC/VAC
Rated Power	350	W
Inverter Efficiency	93	%

6.2. Economic Analysis Results

Table 6 below shows the economic analysis of the proposed system, as presented in previous section. Based on the analysis, initial cost for equipments, installation and structure is RM 39,559.79. Then, present value of operation and maintenance is RM 3,884.06, and replacement cost is RM 259.72. Salvage value for the whole system is RM 7,911.96. Hence, LCC for 20 years is RM 35,791.61, and annual LCC is RM 3,645.46. E_{PV} for the proposed system is 1828.305 kWh. Therefore, from the result, LCOE calculated is RM 1.98/kWh.

Table 6 Economic Analysis

Discount / Interest Rates	4.60%
Inflation Rates	3.40%
Net Discount Rates, k	8.00%
Components	**RM**
Initial Cost	
Energy Equipment	
PV Module(s)	7089.36
Electrolyser	1489.40

H_2 Storage Tank	11225.17		
PEMF	292.00		
Inverter	560.71		
Balance of Equipment			
Module Support Structure & System Installation	4480.00		
Miscellaneous			
Contingencies	391.69		
TOTAL INITIAL COST	39559.79		
O&M Cost			
LCC O&M$_m$	395.60		
OPERATION & MAINTENANCE	3884.06		
Replacement Cost			
Inverter			
LCC inverter$_{n1}$	259.72	n1	10
INVERTER REPLACEMENT	259.72		
Salvage			
SALVAGE VALUE	7911.96		
RESULT			
LCC Cost for 20 Years	35791.61		
LCC Cost / Year	3645.46		
Cost of Energy	1.98		

6.3. Comparison with SAPV with AGM battery system sizing

The current results is compared with conventional sizing method and economic analysis of SAPV system with AGM battery, which published in 2014 [28]. The result from the study shows that the LCC for the proposed system is RM 34,232. Meanwhile, LCC for a year is RM 3,206.82 and LCOE for the respective case is RM 1.76/kWh. Table 7 shows the comparison of current findings with previously published results.

Based on the table, it is shown that the LCC, annual LCC and LCOE for SAPV system with hydrogen storage has higher expenditure compared to the published findings. For AGM battery, it need to be replaced each 5 years. Meanwhile, the hydrogen storage, the PEME, H_2 Tank and PEMFC do not have to be replaced because the lifetime is longer, which is 20 years [18]. However, the initial cost for hydrogen storage is very high because fuel cell efficiency is quite low (60%). Therefore, bigger hydrogen storage capacity is needed in order for hydrogen storage provide back-up energy similar with AGM battery during insufficient PV generation.

Table 7 Economic Analysis

	SAPV with Hydrogen Storage	**SAPV with AGM Battery [28]**
LCC Cost for 25 Years (RM)	35791.61	34231.98
LCC Cost / Year (RM/year)	3645.46	3206.81
Cost of Energy (RM/kWh)	1.98	1.74

7. CONCLUSION

A sizing and economic analysis of SAPV system with hydrogen storage has been presented. A small scale of household load requirement and daily's average of solar radiation was used to design an off-grid PV system. Economic assessment is by employing life cycle cost and levelized cost of energy analysis. The result shows that, LCC for the proposed system in 20 years is RM 35,791.61. Meanwhile, LCC for a year is RM 3,645.46 and LCOE value obtained is RM 1.98/kWh.

However, compared to previously published results [28], the expenditure for SAPV system with AGM battery is lower, where LCC for the system is RM 34,232, annual LCC is RM 3,206.82 and the LCOE for the respective cases is RM 1.76/kWh. Based on current findings, even though hydrogen energy storage has high energy density per mass, the system has low efficiency as a storage and still expensive. However, as an emerging commercialize product, the manufacturers and researchers can focus on how to increase storage system efficiency for the future usage.

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REFERENCES

[1] A. Mellit and S. A. Kalogirou, "Artificial intelligence techniques for photovoltaic applications: A review," *Progress in Energy and Combustion Science*, vol. 34, pp. 574-632, 2008.

[2] S. I. Mustapa, L. Y. Peng, and A. H. Hashim, "Issues and challenges of renewable energy development: A Malaysian experience," in *Energy and Sustainable Development: Issues and Strategies (ESD), 2010 Proceedings of the international conference on*, 2010, pp. 1-6.

[3] M. Castañeda, A. Cano, F. Jurado, H. Sánchez, and L. M. Fernández, "Sizing optimization, dynamic modeling and energy management strategies of a stand-alone PV/hydrogen/battery-based hybrid system," *International Journal of Hydrogen Energy*, vol. 38, pp. 3830-3845, 2013.

[4] W. Zhou, C. Lou, Z. Li, L. Lu, and H. Yang, "Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems," *Applied Energy*, vol. 87, pp. 380-389, 2010.

[5] N. Barsoum and P. Vacent, "Balancing cost, operation and performance in integrated hydrogen hybrid energy system," in *Modelling & Simulation, 2007. AMS'07. First Asia International Conference on*, 2007, pp. 14-18.

[6] D. L. King, W. E. Boyson, and J. A. Kratochvil, "Analysis of factors influencing the annual energy production of photovoltaic systems," in *Photovoltaic Specialists Conference, 2002. Conference Record of the Twenty-Ninth IEEE*, 2002, pp. 1356-1361.

[7] (23rd February). *PVsyst: Software for Photovoltaic System*. Available: http://www.pvsyst.com/en/

[8] W. Shen, "Optimally sizing of solar array and battery in a standalone photovoltaic system in Malaysia," *Renewable Energy*, vol. 34, pp. 348-352, 2009.

[9] M. Hankins, *Stand-alone Solar Electric Systems: The Earthscan Expert Handbook for Planning, Design and Installation*: Earthscan, 2010.

[10] (20 May 2014). *PV Modules in a String*. Available: https://nationalvetcontent.edu.au/alfresco/d/d/workspace/SpacesStore/4e1e0e97-bc55-4c44-a692-4d31f4d0d934/13_02/content_sections/learn_about/08_solar_page_010.htm

[11] H. Tebibel and S. Labed, "Design and sizing of stand-alone photovoltaic hydrogen system for HCNG production," *International Journal of Hydrogen Energy*, vol. 39, pp. 3625-3636, 2014.

[12] D. Ipsakis, S. Voutetakis, P. Seferlis, F. Stergiopoulos, and C. Elmasides, "Power management strategies for a stand-alone power system using renewable energy sources and hydrogen storage," *international journal of hydrogen energy,* vol. 34, pp. 7081-7095, 2009.
[13] A. Nafeh, "Design and Economic Analysis of a stand-alone PV system to electrify a remote area household in Egypt," *Open Renewable Energy Journal,* vol. 2, pp. 33-37, 2009.
[14] R. Jallouli and L. Krichen, "Sizing, techno-economic and generation management analysis of a stand alone photovoltaic power unit including storage devices," *Energy,* vol. 40, pp. 196-209, 2012.
[15] S. I. Sulaiman, T. K. A. Rahman, I. Musirin, and S. Shaari, "Sizing grid-connected photovoltaic system using genetic algorithm," in *Industrial Electronics and Applications (ISIEA), 2011 IEEE Symposium on*, 2011, pp. 505-509.
[16] V. Applasamy, "Cost evaluation of a stand-alone residential photovoltaic power system in Malaysia," in *Business, Engineering and Industrial Applications (ISBEIA), 2011 IEEE Symposium on*, 2011, pp. 214-218.
[17] W. G. Sullivan, E. M. Wicks, and J. T. Luxhoj, *Engineering economy*: Pearson Prentice Hall, 2009.
[18] E. Zoulias and N. Lymberopoulos, "Techno-economic analysis of the integration of hydrogen energy technologies in renewable energy-based stand-alone power systems," *Renewable Energy,* vol. 32, pp. 680-696, 2007.
[19] C. S. Park, P. Kumar, and N. Kumar, *Fundamentals of engineering economics*: Pearson/Prentice Hall, 2004.
[20] (1 December 2014). *Malaysia Inflation Rate*. Available: http://www.tradingeconomics.com/malaysia/inflation-cpi
[21] (1 December 2014). *Bank Lending Rates*. Available: http://www.blr.my/
[22] S. Kamel and C. Dahl, "The economics of hybrid power systems for sustainable desert agriculture in Egypt," *Energy,* vol. 30, pp. 1271-1281, 2005.
[23] D. Näsvall, "Development of a model for physical and economical optimization of distributed PV systems," 2013.
[24] (20 May 2014). *Sealed-AGM Batteries*. Available: http://www.wholesalesolar.com/products.folder/battery-folder/Surretterolls.html#SealedAGMBatteries
[25] (20 May 2014). *140 Watt BLACK FRAME Solar Panel*. Available: http://www.ecodirect.com/Kyocera-KD140GX-LFBS-140-Watt-PV-Panel-p/kyocera-kd140gx-lfbs.htm
[26] (20 May 2014). *Blue Sky Energy*. Available: http://www.blueskyenergyinc.com/pricing/
[27] (20 May 2014). *350 Watt 24 Volt Inverter / Pure Sine Wave*. Available: http://www.ecodirect.com/Cotek-SK350-124-350W-24V-Pure-Sine-Inverter-p/cotek-sk350-124.htm
[28] N. D. Nordin and H. A. Rahman, "Design and economic analysis in stand alone photovoltaic system," in *Energy Conversion (CENCON), 2014 IEEE Conference on*, 2014, pp. 152-157.